

# Exploring the early and late-type galaxy populations using the Sloan Digital Sky Survey

PhD theses

Zsuzsanna Győry



Budapest

2008

Győry Zsuzsanna  
Komplex Rendszerek Fizikája Tanszék  
1117 Budapest, Pázmány Péter sétány 1/A  
gyory@complex.elte.hu  
Eötvös Loránd Tudományegyetem  
Természettudományi Kar  
Fizika Doktori Iskola  
Részecskefizika és Csillagászat program  
Doktori iskola vezetője: dr. Horváth Zsolt  
Programvezető: dr. Csikor Ferenc  
Témavezető: dr. Csabai István  
2008. szeptember 1.

## 1. Introduction

Extragalactic surveys are one of our most important windows to the Universe. The Sloan Digital Sky Survey (SDSS) is a unique initiative to explore 1/4 of the sky and record and process spectral and photometric data of galaxies, quasars and stars through sophisticated software pipelines.

One of the important pipelines assigns magnitudes measured through five different broad band filters to each observed object. The depth of this survey enables statistical analyses beyond any of its predecessors, but it also challenges us to extract as much information out of these few numbers as possible. The expensive spectrum measurements of nearby galaxies provide the necessary information for calibration. Redshift and nebular emission activity is directly visible from the spectrum, but also other observables are available, such as age and metallicity.

The spectrum or the locus in color space is not the only hint we get from a galaxy. The imaging pipeline of SDSS records morphological information which can be quantified through various fitting procedures. The most straightforward morphological classification distinguishes between early type elliptical galaxies and late type spirals. The class of a galaxy in these categories manifests in several other physical features as well. Early type galaxies are mostly red and possess a characteristic non-scale invariant spectrum. Late type galaxies are more blue, and the strong emission lines indicate ongoing star formation activity. Other relations of color and structure may give us clues to galaxy evolution.

In my thesis I explore the galaxy populations in the two types, discuss

their color space distribution, nebular emission spectra, their evolutionary connection, and some practical consequences of their different nature in special photometric applications.

After introducing the Sloan Digital Sky Survey I use its photometric data to quantify the strong bimodality of the galaxy distribution function in color space.

Numerous recent studies of galaxy distribution and evolution were motivated by this phenomenon. Observations have found evidence of strong evolution of the distribution of galaxy populations. At least half of the red galaxies have assembled their final form since  $z = 1$ . The observations confirm the evolution from late to early types, but are in contradiction with the passive evolution scenario and require transitions via merging and subsequent truncation of their star formation in late type galaxies. One of the key predictions of this hypothesis is a correlation between stellar population and merger induced tidal structure in early type galaxies, more structured objects having younger stellar populations. I analyzed several aspects of this prediction.

My research has been strongly motivated by photometric applications, with a special focus on improving the photometric redshift estimation method. The differences in the two galaxy types raise a number methodological problems, most of them affecting the blue population. Unlike the early types, the blue galaxies have a spectrum which is close to scale-invariant. This induces degeneracies which make their redshift estimation difficult. The red and blue luminosity functions are different too, blue galaxies having statistically fainter absolute magnitudes. This causes that blue galaxies in naively selected samples will have fainter magnitudes, which means larger photometric errors, or they will be underrepresented. This has a negative impact

on both the calibration and the application of the photometric redshift estimation. A special problem in the spectral template based methods is the lack of physically calibrated emission lines in the templates. This causes discrepancies when fitting blue galaxies having significant star formation. I address some of these issues in my thesis in order to make the photometric redshift estimation work equally well for all galaxy types.

## 2. Theses

I summarize the main results of my thesis as follows.

1. I studied the distribution of SDSS galaxies in the four dimensional color space. I applied a classificatoin based on Bayesian probability analysis. I have found that the distribution can be accurately modeled with classes that can be naturally mapped into the two classes of red and blue galaxies. With this I have justified the bimodal description of the distribution. I have refined the description of the color space separation of galaxies by determining the hypersurface separating the two main groups. I have justified the simple linear cut  $u - r = 2.22$  and its stability to nonlinear corrections.
2. I have constructed a volume limited nearby galaxy sample of controlled, high completeness. Applying a Sérsic light-profile fit I have identified early type candidates, which were then visually classified and filtered

to select E/S0 galaxies. I have designed and implemented an asymmetry measure as a robust and repeatable indicator of tidally-induced structure in early-type galaxies.

3. I studied the correlations of structure and stellar population in early type galaxies. I have reproduced the landmark correlation of Schweizer & Seitzer (1992) in color and asymmetry (more asymmetric objects tend to be bluer). I have shown for the first time that the correlation is driven by the age of the stellar population. The metallicity had no detectable correlation with asymmetry, rather increased the scatter in color.
4. I used a set of stellar population models motivated by the merger scenario that reproduce the evolution of red sequence galaxies and are consistent with present-day colors/ages. This showed that my results are qualitatively consistent with the merger hypothesis: the light weighted age and asymmetry both correlate with the time of the last merger event, but with large scatter, therefore the determination of the individual merger ages is impossible. However, I have demonstrated that, in statistical sense, an important fraction of the bluest E/S0 galaxies must have experienced recent mergers.
5. I studied the dimensionality of emission lines using principal component analysis. I have found that they can be accurately represented using three orthonormal eigenvectors. In this subspace the galaxies are localized to an approximately two-dimensional manifold. The red and blue classes can be clearly separated in this basis, the classification by stellar population agrees with the classification by nebular emission in  $\sim 90\%$ . I have identified the main physical trends spanning the two-

dimensional locus: the relative strength of the emission lines (connected with star formation rate) and the metallicity.

6. Using the eigenspace representation of emission lines and of the continuum spectra I studied the correlations. I have established an empirical relation, which gives the most likely emission pattern and its statistical scatter as a function of the continuum parameters. I implemented this prescription to add emission lines to spectral models not including nebular emission. With the same method I have modified the empirical spectra of Coleman, Wu & Weedman(1980), and I applied them to improve the photometric redshift estimation of late type galaxies.
7. I investigated the suitability of the Bruzual-Charlot models in template based photometric redshift estimation. I found that the spectroscopically selected templates induce severe, systematic discrepancies. With an optimizing algorithm I have selected a set of model spectra which yields a photometric redshift estimate more accurate than the hybrid template fitting method.
8. I studied the precision of the SDSS photometric redshift estimation by a comparison with COMBO-17 data. Using the data of the main spectroscopic sample, luminous red galaxies and the special photo-z plates of SDSS Southern Survey which targeted blue, distant galaxies, I have constructed a training set uniform in redshift and type. Using this I improved the precision of the redshift estimator especially for the fainter blue galaxies. I combined these modifications with the emission line correction of point 5. and created the template spectra used in the SDSS photometric redshift estimation since DR4.

## Publikációk

Strateva, I., Ivezić, Z., Knapp, G. R., Narayanan, V. K., Strauss, M. A., Gunn, J. E., Lupton, R. H., Schlegel, D., Bahcall, N. A., Brinkmann, J., Brunner, R. J., Budavári, T., Csabai, I., Castander, F. J., Doi, M., Fukugita, M., Győry, Z., Hamabe, M., Hennessy, G., Ichikawa, T., Kunszt, P. Z., Lamb, D. Q., McKay, T. A., Okamura, S., Racusin, J., Sekiguchi, M., Schneider, D. P., Shimasaku, K., York, D., „Color Separation of Galaxy Types in the Sloan Digital Sky Survey Imaging Data”, 2001 *Astronomical Journal*, 122, 1861

Csabai, I., Budavári, T., Connolly, A. J., Szalay, A. S., Győry, Z., Benítez, N., Annis, J., Brinkmann, J., Eisenstein, D., Fukugita, M., Gunn, J., Kent, S., Lupton, R., Nichol, R. C., Stoughton, C., „The Application of Photometric Redshifts to the SDSS Early Data Release”, 2003 *Astronomical Journal*, 125, 580

Zsuzsanna Győry, Alexander S. Szalay, Tamás Budavári, István Csabai, Stéphane Charlot, „Correlations between Nebular Emission in SDSS Galaxies and the Continuum Spectral Shape”, *AJ* submitted

Zsuzsanna Győry, Eric Bell, „Testing a prediction of the merger origin of early-type galaxies: a correlation between stellar populations and asymmetry”, *ApJ* submitted